YOU AND THE ATOM

SPECIAL STUDENT EDITION

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BY GERALD WENDT

The development of atomic energy, its peace time applications, its fundamental importance for everyone in the world, explained in simple, non technical language by an expert in the field of scientific reporting.



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With a preface by Luther H. Evans. Director-General of United Nations Educational, Scientific and Cultural Organization.

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Contents

Preface

Almost any new discovery in science may be used for good or for evil. It is men who decide, according to their needs of the moment, and according to their moral and philosophical concepts. With peace now prevailing, with the peoples of every nation eager for the good life, and with ample knowledge now available from fifteen years of research, the time is certainly ripe for developing the beneficent and constructive uses of the atom for peace. The proposal to do so by international cooperation was unanimously approved by the General Assembly of the United Nations in December 1954 and by the General Conference of UNESCO at its eighth session. The first major event was the United Nations Conference on the Peaceful Uses of Atomic Energy, held in Geneva in August 1955, ten years after Hiroshima.

Thus a new era opened. The science of atomic materials and the engineering uses of atomic energy will be shared by all the world. It becomes as important for the public to learn the new facts as it has been to understand the use of coal and steam. The new power will be widely used long before school textbooks can be rewritten and before the children who study them can become adults.

An introduction to the new knowledge and to its use in ordinary, peaceful living is needed at once, especially for the educators—those who teach in schools and those who write for the public as well.

The United Nations Educational, Scientific and Cultural Organization is charged with the enhancement of peace through international cooperation in education and in science. Therefore, to mark the occasion of the Geneva Conference, UNESCO takes pleasure in publishing this book on a great development that promises to improve the standard of living of all mankind during the years just ahead.

LUTHER H. EVANS
Director-General

Introduction

THE ONE FACT that makes the atomic bomb a unique weapon—if we may begin with an unattractive subject in order to understand an attractive one—is that it contains an enormous amount of energy in a very small package and releases that energy at tremendous speed. It represents concentrated energy, several million times as concentrated as in any form previously known. The total amount of energy in a bomb is not as great as man has used or felt in other forms. A few thousand tons of coal contains as much. A thunderstorm releases much more. The sunshine that lifts millions of tons of water from the sea high into the clouds exerts immeasurably greater energy. But in these forms it is spread thin. In the bomb it hides quietly in a few pounds or kilograms of the "atomic" material, then suddenly releases it in a very small space and in an instant of time. That is what is needed in an explosion and this is the fastest and most powerful of all.

But such quick use of concentrated energy is a rare and abnormal thing, limited to wartime destruction. Milder explosives have peaceful uses in the quarrying of stone, the boring of tunnels, or the blasting of under-

water channels for ships—wherever concentrated energy is needed to undo the intense cohesion of solid rock. In ordinary living, however, the concentration of energy has no importance. It is the amount that matters, and the availability and the cost. Nor does the speed of releasing the energy matter. The fire on the hearth or in the stove can burn for hours to heat the house or roast a chicken. The engine in the automobile delivers the energy of the fuel to the wheels swiftly or slowly depending on the traffic and the haste of the driver—but never in seconds, always in minutes or hours. Peaceful, everyday life gets its energy slowly and in small quantities from fuels, not from explosives. That is the contrast between peace and war. This is a peaceful book; we need not think of the bomb again.

To apply atomic energy to the uses of peace means producing an atomic fuel and making it available in industry, in city life, in the home and on the farm. The question is not how powerful or how fast but how cheap, how readily obtained and used, and how and when? These are the questions discussed among scientists at the United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva, in August of 1955. The answers are not obvious; they require the study of experts. Today only a relatively few men can answer them, partly because they involve facts and principles that were unknown ten or twenty years ago, and therefore are not in the schoolbooks of science. But it is also partly because much of the new knowledge was discovered and applied during a period of international tensions when secrecy was a general policy, even among scientists, so that the research men and engineers of different nations have developed somewhat different versions and interests which must be combined into a full world-picture.

Furthermore, there are the by-products of the nuclear reactors, the hundreds of radioactive elements and chemicals, called "isotopes," which already have thousands of uses in medicine, agriculture and industry by virtue of the distinctive rays that they emit. Even with the limited quantities now available, the savings effected by their use in agriculture and industry already amount to many millions of dollars and the advances in medicine and biology are of untold value. Their output will increase and their cost will decrease as nuclear furnaces begin to operate for peaceful energy production. These radioactive by-products may prove as valuable to humanity as nuclear energy itself. But their use today is in its infancy and is scattered through hundreds of research laboratories and hospitals throughout the world. A mutual understanding of the possibilities and the techniques used in different sciences must precede their full utilization and is an important part of the Geneva Conference.

It is significant that this is happening under the auspices of the United Nations. The many friendly contacts that the nations of the earth had with each other during the past ten years have cemented a world organization which is ready to sponsor the development of a great new international resource. The consequences of its use will in the course of time probably improve the conditions of life in all parts of the world and will certainly change them. Such new resources have appeared in the past, and notably the discovery of America and the invention of the steam engine. But never before have they been studied in advance as a whole by the world as a whole. It marks a new era.

Public interest in the discussions of the Geneva Conference is thus entirely justified, for they will eventually affect almost every one. Yet they are in the language

of science, indeed in the relatively new language of the atomic sciences, full of words that have no meaning to the average person in any country. Even when interpreted into the language of newspapers and the radio they can be puzzling. Nevertheless this new form of energy is a social force that cannot be left entirely to the scientists. Its uses must be governed by and for the people. And so thinking people in all lands want to understand it. This means that they must make some effort to study it, for there is no royal road to learning.

The international roads to learning, to education, science and culture, are mapped and posted by UNESCO. This book is a guidebook to the newly discovered land of atomic energy in which the scenery is all science and the roads are education.

CHAPTER 1 *Energy*

ANY BOOK ON a scientific subject resembles a guidebook in one practical way: it is impossible for the author to make allowances for how much the reader already knows. Most readers will know nothing about the strange land; others have made a quick trip and know the major landmarks; still others have been there often but want to consult the road map for details or want to know the most recent changes. It would be best to write a separate guide for each. A single book for all may bore the experienced traveler with things he already knows or, on the other hand, it may puzzle the newcomer by omitting the elementary facts. Since most people are strangers in the world of science, a general book is written for them. Other readers can skip the parts they already know, as everyone does with a guidebook. So it is best to begin at the beginning.

Energy is a rather difficult thing to define. Indeed it is not a thing at all. It does not exist in tangible form as matter does. It occupies no space, has no weight and throws no shadow. In short, it is not material as all objects are. Instead, it is the principle of action. It is

involved in every motion, in every event. In ordinary experience it does not exist in pure, detached form but is always attached to or contained in some material object or particle. A flying ball has energy by virtue of its motion. If it hits another ball and sets that ball in motion it gives part of its energy to the second ball.

Energy occurs in many forms besides visible motion. Steam under pressure has energy in the form of heat. This means that the molecules, the ultimate particles of water that compose the steam, are in rapid motion. When the steam in an engine expands by pushing a piston, it cools and loses heat energy which becomes the mechanical energy of motion in the engine. The engine may turn a dynamo and thus set electrons in motion, thus generating electrical energy in the form of an electric current. This may, in turn, be used to set a motor spinning, whereby the energy becomes mechanical once more. Or the electricity may pass through a wire where it turns to heat again. If the wire is raised to a high enough temperature the wire becomes luminous and part of its energy radiates off as the energy of light. Light seems to be the purest form of energy because it is not attached to material particles in the ordinary sense but is composed of a stream of ethereal particles, called photons, that enter our eyes direct to stir the sense of sight.

Enormous amounts of light, or radiant energy, are generated on the sun and stream across empty space at a speed of 186,000 miles per second to strike the earth and turn their energy into heat when and where they strike. But green leaves, quite alone among the materials of the earth, can absorb the energy of light and use it to produce a chemical reaction. It is one in which two simple gases that are present in the atmosphere, and in the leaves, are each forcefully torn apart, bereft of some of

the oxygen they contain, and are combined to form the more complex chemicals that become the substance of the plant. Thus the carbon dioxide of the air and the water from the air and the soil are combined to form sugars, starches and cellulose. Every year sunlight manufactures for mankind some 10,000 million tons of wood, which is chiefly cellulose, to say nothing of many hundreds of millions of tons of wheat, rice and other foods, that are chiefly starch. These materials contain energy in still another form, called chemical. It is not energy of motion but lies in the tight bonds that have been forged from sunlight by the living plant to hold the atoms together in the molecules of cellulose and starch. Chemical energy is stored energy, somewhat like energy of elasticity that is stored in a spring when it is tightly wound by external force.

In such forms energy may best be defined as the capacity for doing work. It may be quietly and invisibly stored in the spring, in a fuel, or in snow piled high on a mountain, but it can be released to generate motion, heat or electricity to do man's work. Technically, it is energy that does the work, while power is the rate at which the work is done. A powerful man or engine does not do more work than a smaller one but does it in less time. The total work depends on the amount of available energy; the speed with which the energy is spent and the work is done measures the power.

Fuels

Like the stored energy of a coiled spring, chemical energy can be released when the bonds are loosened. In the case of plant materials this can easily be done by heating them. Adding heat raises the temperature,

which is to say that it increases the vibration and motion of the molecules. This itself loosens the bonds that held them together so that they decompose into vapors and charcoal. But if there is access to the oxygen of the air the vapors combine chemically with the oxygen to form water and carbon dioxide once more. In other words, putting a match to vegetable material sets them on fire. They burst into flame and the heat of the flame comes from the stored chemical energy which, in turn, came from the sun. Careful measurements have shown that the heat energy evolved in combustion is exactly equal in quantity to the light energy used by the plant to produce the burned material. Thus fuels are chemical storehouses of energy held ready for man's use.

Wood was once the universal fuel, even for railroads, and in some parts of the earth it still is. But modern industry is based on coal which is fossil wood that grew in lush tropical swamps many thousands of years ago, died and fell to be decomposed and compressed under layers of soil and sand that became rock with the passage of countless centuries. So coal still contains the chemically stored energy of ancient sunlight. It is more valuable than wood as industrial fuel because it is more compressed and concentrated, contains little water or air, thus provides more energy per pound than wood does. Much the same is true of petroleum, which is the residue of sea plants and animals, decomposed and concentrated deep below ancient seas. Both of these fuels are valuable because of their energy content, because they can easily be transported to the ends of the earth, and because they can be made to deliver their energy precisely where and when it is wanted for use—in the case of oil even drop by drop in the engine of an automobile.

Foods

Foods are fuels too, chemically speaking, because they provide the animal body with energy for its action. It is true that they also provide the materials for the growth and repair of the body, but the larger part of all food is simply burned to provide energy. It does not burn with a flame at high temperature, as fuels do, because of the marvelous ability of the body to conduct combustion—or more correctly, oxidation—without an increase of temperature. But starches and sugars, fats and proteins are nevertheless burned in the body as truly as is motor fuel in an engine. Their complicated molecules are broken up into simpler ones, they encounter oxygen brought from the lungs by the blood stream and they combine with it to form carbon dioxide and water which are excreted. In the process the muscle and nerve cells of the body take up and use the energy to do their work and to keep the body warm.

Foods are often evaluated by their energy value, measured in calories. A calorie is the amount of energy needed to heat a kilogram of water by one degree centigrade. The minimum number of calories considered necessary to keep a human being healthy is about 3,000 per day. A pound of bread provides about 1,200 calories; a pound of sugar 1,800. Two or three pounds of food per day, depending on the proportion of carbohydrates and fats, provides enough energy for an average day's work, though men at heavy labor use more.

Chemical Energy

The energy that is stored in foods and fuels is not merely soaked up in them like water in a sponge. It is

an inherent part of them; it is built into their structure and makes them what they are. It is therefore located within the ultimate and smallest possible particle of their chemical structure. These particles are known as molecules. Far too small to be seen, even in the best microscopes, they are the units of which all materials are made. Anything that can break them down also destroys the substance and breaks it down into simpler ones, as when combustion in a fire forms smoke and ash, carbon dioxide and water, or the process of living forms carbon dioxide and water. The fact that energy is liberated indicates that the products of the oxidation (carbon dioxide and water) contain less energy than did the original materials. Putting it the other way about, a combustible material and the oxygen of the air, separately, contain more energy than when they have gone through the chemical reaction of combustion, or oxidation, and have been transformed into carbon dioxide and water.

The energy comes from the bonds that have held together the atoms in the molecules of the combustible material. Actually, these bonds consist of electrons circling about in orbits at the surface of the atoms, much as planets circle about the sun. The energy for combustion and for living comes from the energy of the electrons. When the outer electrons of an atom of carbon or of hydrogen encounter those of an atom of oxygen, they combine their orbits into simpler and more stable ones that require less energy to maintain themselves. The excess energy, now no longer needed, escapes from "storage" and becomes usable, usually as heat for doing work.

The energy obtained from all fuels and foods is thus a product of their atoms just as truly as is that new form of energy from a new type of fuel that is often called

"atomic." It is the new energy that is misnamed. It comes from deep within the atom, from its nucleus, as is described in Chapter 2, and it should be called "nuclear" for that reason. In sudden surprise when it was first released at Hiroshima, speakers and writers called it "atomic" perhaps because atomic sounded mysterious enough and few people had ever heard of the nucleus of the atom. But a new science inevitably introduces new words into the common language, including the word "atom" itself, and "electron," and now "nucleus."

The atomic theory was first introduced into chemistry 150 years ago. But atoms have provided man with energy from their surface electrons since fire was first put to use. Indeed, they have been used for energy since the first tiny sea animal many millions of years ago ate a speck of a green plant to sustain its life. All chemical energy is truly atomic. This book therefore uses the correct term, "nuclear," for the energy and the power that are its topic.

CHAPTER 2 *Nuclear Fuels*

Fundamentals

THE ESSENTIAL FACTS upon which the new age of nuclear energy is based are:

1. In all our previous use of fuels and chemical energy we have touched only the surface of the atom and, by means of chemical reactions, have drawn energy from the surface electrons.

2. All atoms are composed, somewhat like the solar system, of a central nucleus that contains nearly all of the matter and energy of the atom in extremely concentrated form, plus a definite number of electrons that move in distant orbits around the nucleus, like planets about the sun, but leave most of the space within the atom empty.

3. Since the nucleus occupies only a thousandth of a millionth of a millionth of the total volume of the atom, yet contains all the matter or mass, this "matter" must be so dense that it is like nothing in direct human experience—so dense that a solid lump of it (without the empty space) no larger than a drop of water would weigh two million tons.

4. To hold this stuff firmly together in the small individual nuclei (i.e. nucleuses) of the atoms requires a similarly incredible concentration of energy there.

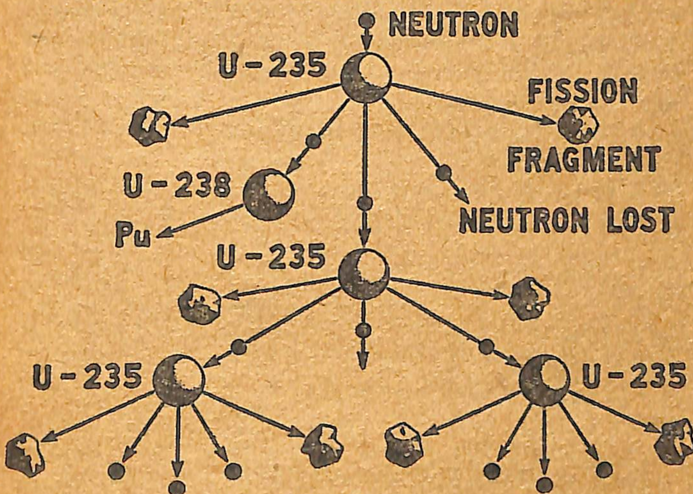
5. In the case of some types of atoms—just a very few of the largest and most complicated, such as uranium—the impact upon the nucleus of a projectile of the right size and the right speed, such as a cosmic ray, can loosen the bonds of the nucleus and cause it to fly apart into fragments that leave the scene at speeds up to 6,000 miles per second and therefore with tremendous energy. This is called fission.

6. The fragments are mostly nuclei of smaller atoms which will pick up electrons to form the atoms of common chemical elements. But some of the fragments are the smallest known particles of matter and appear to be the building blocks of which all nuclei are composed. They include neutrons (which have no electrical charge) and protons (which have a positive electrical charge and are themselves the nuclei of the smallest and lightest atoms, those of hydrogen). The neutrons may be shot out at such a speed that they can cause fission in a second fissionable nucleus and thus start what is called a "chain reaction."

7. If the masses of all these fragments are measured and added, their total is less than the mass of the original large nucleus. Matter has thus been destroyed. It has, in fact, been converted into energy in accordance with the prediction of Albert Einstein's theory of relativity and with his famous equation, $E = mc^2$. This is mathematical shorthand for saying that the energy obtainable from the destruction of a given mass of matter equals the amount of the mass (measured in grams) multiplied twice by the velocity of light (measured in

centimeters per second) Since the velocity of light is 30,000,000,000 centimeters per second, the annihilation of a single gram of matter (about a thirtieth of an ounce) would generate almost as much energy as can be obtained by the burning of twenty million tons of coal. However, the actual fission reactions now obtainable destroy less than one thousandth of the substance of the nuclei.

8. When this nuclear reaction takes place, a small part of the energy is also emitted in the form of radiations that resemble X-rays but are very much more powerful and are able to penetrate through heavy walls of solid matter. They are known as gamma rays, can be destructive to living cells, and are a part of the danger surrounding the conduct of nuclear reactions. But even more



dangerous are the high-speed neutrons which are also able to penetrate through most solid walls.

9. It is possible to control nuclear reactions in properly constructed reactors in such manner that the reaction proceeds safely and smoothly and delivers energy at whatever pace desired.

10. The chemical elements whose nuclei are capable of this fission reaction therefore constitute a new type of fuel that can generate almost three million times as much energy per pound as does any present fuel.

Fission is Rare

The scope of this book does not permit giving more than a bare statement of the above ten points, for this is not a textbook. Any proper teacher of science must disapprove of stating such important facts without any evidence nor even a description of how these conclusions were reached, and of asking the reader to take the writer's word for them. Science is not based on authority but on evidence that convinces all reasonable and competent observers and leads them to agree. Such evidence exists for all the statements here made. But it must be sought in larger books, or, preferably, should be observed in a laboratory of physics. Students and future students may do so. But we must proceed to look at the consequences and to examine further important details.

It is, for instance, an important fact in the prospect for the general use of nuclear energy that the fission reaction is extremely rare. Only the nuclei of some of the largest and heaviest atoms are capable of it. The atoms of iron, aluminum, calcium, silicon, carbon, oxygen, nitrogen and hydrogen, which are the plentiful constituents of the crust of the earth, the sea and the air, are

quite incapable of it. Their nuclei are stable and relaxed, with no energy to spare. This is fortunate for two reasons. If it were not so they would probably not have persisted through some four billion years of the earth's existence but would long ago have disappeared by blowing up. And secondly, small nuclei are the very ones that are produced in the fission of uranium, from which they emerge unscathed. They represent the ashes, so to speak, of the fission of larger atoms and they may perhaps have been produced originally by fission. This fact is the vital guarantee that the nuclear bomb cannot start a chain reaction that could blow up the entire planet. No, the fission reaction is a very special one and fissionable atoms are extremely rare.

In fact there are only two naturally occurring chemical elements that can be used for fission reactions, uranium and thorium. Their atoms are the heaviest and most complex of all. They are both faintly radioactive, which means that, one by one in the course of centuries, their atomic nuclei throw off small fragments, electrons, protons and neutrons so that these two elements are naturally and gradually converted into lead. It has long been assumed that if the earth ever contained any heavier atoms than those of uranium they would be so unstable that they would long ago have decayed into stable, common elements like lead.

This slight instability, this radioactivity, sets these two elements apart from all others, but it is not the same thing as fission, which is the complete rupture of the atomic nucleus with tremendous energy release. This does not occur at all in thorium and, in the case of uranium, only one atom in 140 is capable of it, about 0.7 percent of them. This implies that there are two kinds of uranium atoms, and so there are.

Isotopes

The two varieties of uranium are called isotopes. This strange word comes from the Greek words for "same" and "place." Since it will not long remain strange in the nuclear age, it is well to understand that it refers to the custom, common among chemists, of listing the chemical elements on a chart, called the periodic table, which shows the relation of their chemical properties to the weight and nuclear composition of their atoms, usually one element to a square. It is sufficient here to say that after the discovery of radium by Mme. Curie in 1898, it became evident that a number of elements exist in several varieties whose nuclear structure varies somewhat, so that the weights of the nuclei differ, too. But the net positive electrical charge on the nucleus is the same and so the number of electrons on the surface is also. Thus the chemical properties are the same and all are in the "same place" in the periodic chart. Such varieties were therefore called isotopes.

In the case of uranium, the minerals that occur in nature always contain a mixture of two forms of the element, two isotopes. Both have 92 electrons in their exterior and 92 positive charges on their nuclei to balance. But the weights of their nuclei, and therefore of their atoms, are different. One weighs 238 units, the unit being the weight of a single hydrogen atom. The other weighs only 235. Natural uranium contains 99.3 percent of the heavier isotope and only 0.7 percent of the lighter one, called uranium-235 or, using the common chemical abbreviation, U-235. Only U-235 is fissionable and can be used directly as a nuclear fuel. The first step in making a nuclear fuel from uranium is to separate the two isotopes in order to procure pure U-235.

Ordinarily, different chemical elements can be easily separated from each other by using their different reactions to chemical reagents. So uranium is separated in pure form from all the other elements that occur with it in the mineral. But there is no possible chemical way of separating the two isotopes of uranium; they are chemically identical. But they are so near to each other in physical properties too that any sort of physical separation is also extremely difficult, though not impossible. The chief difference is in the weights of the two varieties of atoms, a difference of only three units in 238, slightly more than one percent. On this basis they can be separated one from another.

Not exactly by weight, however. Strictly speaking, weight is a measure of the pull of gravity on a mass. So it would be better to speak of the mass of the atoms, not the weight, though the difference in mass is the same as that in weight. But mass, not weight, controls the speed of the random, back-and-forth motion of the molecules of any gas. It is always higher at higher temperatures, but at any one temperature the molecules and atoms of smaller mass dance faster. It is this factor that is used to separate the two isotopes of uranium. They are put into the form of a fluoride, which is a gaseous molecule, and this natural mixture is passed over a large barrier with billions of microscopic pores. Both isotopes escape slowly through the pores to the other side, a process known as diffusion. But the lesser mass and higher agitation of the U-235 permit relatively more of it to pass through than of the more massive U-238. Thus the concentration of U-235 is slightly increased. The enriched gas is then passed through another porous wall to enrich it further. After thousands of such repeated passages requiring many months, U-235 is obtained in

almost pure form. Almost incredibly large and costly gaseous diffusion plants are required for this separation but they are essential to the nuclear fuel industry because U-235 is the one and only material found on earth that is capable of direct fission and will start a nuclear chain reaction. All else depends on it.

Artificial Elements

If no elements other than U-235 were susceptible of fission there would be little prospect of a nuclear power industry. The supply would be too limited and too costly. But it was discovered early in the wartime researches that U-235 can be used to produce other types of atoms that do not exist in nature but are capable of fission. Incidentally, the artificial manufacture of these new elements meant accomplishing the dream of the ancient alchemists to change one element into another—lead into gold, for example. Once thought impossible, the manufacture of new elements is now a routine operation in nuclear science and engineering. A large number of new elements and many hundreds of new isotopic forms have been artificially made by means of nuclear chain reactions. Two of them, the new element plutonium and the new isotope of uranium, U-233, are themselves fissionable and are important nuclear fuels.

The process of making them is not simple. It requires first the spontaneous fission of an atom of U-235 in a nuclear furnace or "reactor." When that nucleus breaks up it ejects several neutrons at high speed. They are the active agents in nuclear reactions and one or more of them may hit other U-235 nuclei, causing further fission and thus maintaining the chain reaction. But if one of the neutrons collides with a nucleus of U-238 (which does

not fission) at a proper velocity, a different type of nuclear reaction occurs. The neutron attaches to the U-238 nucleus. Since the neutron has a mass of one, we thus have a new isotope of uranium, U-239. It is not stable, however, and in a matter of minutes its nucleus ejects an electron and becomes a new element which has been named neptunium. This is also radioactive and within a matter of days its nucleus ejects another electron, thus turns into a third new element, named plutonium, which is relatively stable. While it is slightly radioactive, it decays only in many thousands of years. This rather complicated process is automatic so that neutrons from U-235 in effect manufacture plutonium from U-238 and the plutonium collects in the reactor. But plutonium is fissionable. Like U-235 it is a major nuclear fuel.

In quite the same way neutrons from U-235 can transform the natural element thorium into uranium-233, another isotope that is capable of fission. Thus the world's great deposits of thorium minerals also become available for transformation into nuclear fuels, though none are as yet actually being used.

One of the most striking, and fortunate, facts in this story is that the fission of U-235 sets free not merely one neutron but two or three (See page 23). The first one is needed to maintain the chain reaction and thus to generate power. The others are available for the production of plutonium from ordinary U-238. Since there are several of them, it is possible to operate a nuclear reactor so that it manufactures more plutonium than it uses of U-235. This is to say that it manufactures more fuel than it uses. It also means that all of the world's uranium, not merely the 0.7 percent of U-235, thus becomes available for nuclear fuel. These are the factors that make an age of nuclear fuels and of industrial development based on them possible and perhaps practical.

CHAPTER 3 *Sources*

History

Like all materials that man uses, the nuclear fuels come from the earth. But unlike all others, these fuels go through extensive chemical transformations from their natural state as minerals before they are ready for use. The ores that contain uranium and thorium are both rare and are found only in widely separated spots on the earth's surface. Neither had any important use until the discovery of nuclear fission. Uranium had been used chiefly to impart a greenish-yellow fluorescent hue to exotic glassware and other ceramics; thorium was used for the incandescent "mantles" that gave off a pure white light when heated in a gas flame in the days when coal gas or water gas was used for illumination as well as for heating and cooking. When they suddenly become valuable as a source of energy, only small quantities of purified uranium were on hand—and that is still true of thorium.

Uranium had, however, been found and mined as a by-product in the production of radium which was needed for medical use, chiefly in the treatment of cancer. The

weak natural radioactivity of uranium atoms transforms them slowly into lead but on the way they pass through a stage, represented by the radium atom, which is intensely radioactive and persists for some thousands of years before turning into lead. Radium therefore occurs only in uranium minerals and in small amount—about one part in three million of uranium, or one gram in three tons. But radium was then worth more than $100 a gram and so high-grade uranium ores were valuable although the uranium itself was not.

For this reason the richest uranium deposits were found and developed during the early years of this century and were ready for expansion when uranium became valuable. Three were outstanding because in each case the mineral present is pitchblende, in which the uranium is combined with oxygen as a black oxide and the percentage of uranium is high. The first was in the ancient mines at Joachimsthal in the Bohemian area of Czechoslovakia which have been worked for eight hundred years, first for tin, then silver, cobalt and nickel, and finally, after the discovery of radium in the ore in 1898 by Madame Curie, for uranium. A second large deposit turned up in 1915 in the famed Shinkolobwe Mine in the Belgian Congo. Finally, in 1930, a large uranium deposit was found near Great Bear Lake, close to the Arctic Circle in the Canadian Northwest. Both the Congo and the Canadian minerals are rich enough so that they can be transported more than a thousand miles by river steamships before reaching a seaport or a railroad.

New Sources

A second major source of uranium is in more complex minerals, such as carnotite, which occur only in small

pockets hidden and widely scattered in the vast strata of sandstone that cover the high and arid Colorado Plateau in the United States. These too were used as sources of radium and, in fact, provided most of the world's supply until the richer deposits in the Belgian Congo were developed. When the demand for uranium recently became pressing the search for carnotite pockets spread over the entire 130,000 square miles of the plateau and large numbers of them were found, many of them small and close to the lower limit of usefulness, which is two pounds of uranium per ton of ore. The total thus located, however, is impressive. Similar deposits have been found elsewhere in the United States and in many other parts of the world. Two of the most promising are at Rum Jungle in the Northern Territory of Australia and at Radium Hill in South Australia.

A third souce of uranium is in rocks that are quarried, crushed and treated for other products which thus bear the cost so that much smaller concentrations of uranium become usable. Uranium is, in effect, a by-product. Examples are the gold mines of South Africa and the phosphate-rock quarries in the southeastern United States. In both cases the uranium content of the rock is low but the costs of extraction are also so low, under the circumstances, that they are both producing important amounts of uranium.

More uranium ores will certainly be discovered, for it is a metal that is very widely distributed in the earth's crust. It has been estimated that it amounts to one part in 250,000. In that case uranium is almost as plentiful as lead or zinc and a hundred times as plentiful as silver. In fact there are, in addition, five tons of uranium in every cubic mile of sea water. When the amount of uranium is less than 0.1 percent, however, the extraction

of the metal is too expensive. Nevertheless its wide distribution is an indication that deposits of higher concentration will continue to be found in unexpected places and amounts.

The net result is that in the known and usable minerals of uranium from twenty-five to fifty times as much energy is available as in all the coal deposits of the world. It is therefore entirely practical to consider uranium as a world fuel to replace coal.

Thorium minerals can also become an important source of nuclear fuels, though none are as yet being so used. This metal is much rarer than uranium and its minerals are not widely spread. The known deposits, however, are relatively large. On the shores of Travancore, near the southern tip of the Indian peninsula, is an extensive area of monazite sand which is at present the world's richest source of thorium. A plant to extract it from 1,500 tons of sand a year is already in operation. There are also smaller deposits of monazite in Brazil.

Extraction

The ores of uranium contain only two to ten pounds of the metal in every ton. This small amount, usually distributed through the ore in microscopic particles, must be freed from nearly 2,000 pounds of useless rock. This requires first crushing the rock in giant crushers, then grinding it into a fine sand. It is then ready for chemical processing which, in the case of carnotite, involves roasting it with salt at a temperature of about 1,000°F., then washing it with water, followed by repeated treatments with acid, heating and drying. After many days of exhaustive treatment the product is a grayish-black

powder, crude uranium oxide, just a few pounds of it from every ton of original ore.

The next stage is its complete purification from all traces of other metals, some of which persistently accompany uranium through most of the chemical processes. Repeated special treatments with acid, however, eventually remove them to give a brown oxide of pure uranium. Then the oxygen must be eliminated and replaced by fluorine, which forms uranium fluoride, a greenish powder known as "green salt."

The green salt is then the raw material from which uranium itself is made, a bright, hard, dense metal, weighing two-thirds of a pound per cubic inch, 50 percent more than lead. It is much like nickel in appearance, though it tarnishes with a gray rust when exposed to the air. It is rolled into long rods that are cut into four-inch lengths that weigh about four pounds each. These are sealed into tight-fitting aluminum cans to protect them from the air. In this form the uranium is at last ready for the nuclear reactor.

Separation

But this is natural uranium, a mixture of the two isotopes, U-238 and U-235. If they are to be separated in order to produce pure U-235, the process starts with the "green salt" mentioned above. Under treatment with additional fluorine it is transformed into uranium hexafluoride, so named because its molecules contain six atoms of fluorine for every atom of uranium. This is the only compound of uranium that can be put into gaseous form, which is necessary if the two isotopes of uranium are to be separated by gaseous diffusion, as described in the previous chapter. At ordinary tempera-

ture uranium hexafluoride is a very corrosive solid but at higher temperatures it evaporates into a heavy gas. Kept hot now, it is permitted to diffuse slowly and repeatedly through the porous walls of many miles of tubing. After months thus spent in the gaseous diffusion plant, it emerges as the hexafluoride of pure U-235 which is finally reduced to the metallic form.

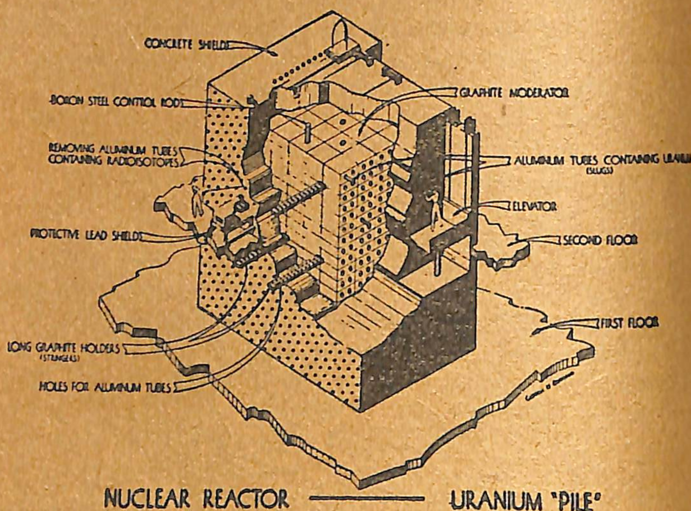
Uranium-235 is the fundamental nuclear fuel because it is the only fissionable material that occurs in nature. It can be used directly for the generation of energy or it can be used in the fission reaction to convert uranium-238 into plutonium. This is the second and only other fissionable nuclear fuel. Its production, however, can be accomplished only by the operation of a nuclear reactor and is therefore considered in the next chapter. Eventually, as the nuclear power industry grows, thorium will also be converted in nuclear reactors into the fissionable uranium-233, thus adding a third fuel to the energy resources of the nuclear age.

Obviously the production of nuclear fuels from the ores is complex and costly. It requires as much special knowledge and skill on the part of the chemist as the reactors demand of the physicist. And it requires very large quantities of highly specialized and intricate metallurgical and chemical equipment which can be provided only by a well-developed chemical-equipment industry. These facts, together with the fact that uranium ores occur in only a few of the world's nations, indicate that nuclear fuels will not be produced for some time to come by most nations but will have to be made available by the few producers to those many nations who will base their power development on them.

CHAPTER 4 *Reactors*

TO THE PLAIN citizen or farmer in any country the coming of nuclear power will mean simply more electrical power. Electricity will be available where there now is none; elsewhere it will mean an increased supply; often it will be cheaper than now. It will flow as now, through wires that lead out from large generators. Like the present hydroelectric stations, they will be massive and technically complex, built at great cost by the government or by large corporations, and operated by a small number of highly specialized engineers and scientists. But instead of converting the energy of swiftly falling water released from a confining dam, they will convert the energy of vastly swifter nuclear particles released from their bonds within the atoms under precisely controlled conditions in nuclear reactors.

Such a reactor is often referred to as an "atomic furnace." This is natural because its operating temperature is high, because uranium can be considered the fuel and because the first direct product is steam. But it differs from a furnace in that it needs no air and so can operate for years firmly enclosed in concrete or even under water. Once charged with fissionable material as fuel,



NUCLEAR REACTOR — URANIUM "PILE"

the nuclear reaction proceeds automatically and needs only the proper controls to regulate the rate of energy production to the desired rate.

There are many types of reactors, built for different purposes, and more than thirty of them are now in continuous operation in several countries. Only two of them—one in an American submarine, the other in a small power plant in the U.S.S.R.—serve solely to generate power, but all of them generate heat and are preliminary steps toward power production. They all operate on the same principles and all have five major features in common:

1. *The Core*

At the heart of the reactor is the small mass of the active, fissionable fuel, either uranium-235 or plutonium, the atoms of which explode one by one when hit by a neutron. The fragments fly apart at very high speeds and carry most of the energy which is released as heat. This reaction starts spontaneously, perhaps by the impact of a passing cosmic ray from a distant star. Once begun, the reaction continues because two or three neutrons are also ejected from each exploding atomic nucleus and some of these in turn cause the explosion of neighboring nuclei of other atoms. This is the chain reaction that feeds on its own energy and continues indefinitely, provided only that there are enough fissionable atomic nuclei on hand to maintain the sequence.

2. *The Moderator*

The speed of the neutrons emitted in the explosion of an atom is extremely high, almost as high as the velocity of light. Since the neutrons are electrically neutral they are very penetrating at this velocity and easily escape from the core and even from the reactor. Those that do escape are, of course, lost and useless. For this reason a "moderator" is used to reduce their speed. When neutrons strike the moderator there is an elastic collision, they give part of their energy to the moderator and bounce off at a reduced speed. At this lower velocity they are much more easily "captured" by the uranium atoms to continue the fission reaction.

Such elastic collisions are most effective in reducing the speed of the neutrons when the particle that the neutron hits is not much larger than the neutron itself.

The moderator must therefore be composed of a material whose atoms are small. Heavy metals with large atoms will not do. The most effective moderator is "heavy water." This is the oxide of an isotope of hydrogen ("heavy hydrogen") whose atoms have a weight of two units, while ordinary hydrogen atoms weigh one unit. Ordinary water is the oxide of ordinary hydrogen but in nature always contains a very small proportion (one part in 5,000) of the heavier isotopic form. The latter can be separated only by a long and expensive process so that heavy water costs approximately $100 a quart. Since large quantities are needed, it is seldom used.

The usual moderator is graphite, which is composed of carbon atoms weighing twelve units. While this is twelve times the mass of the neutron, it is much less than that of most common solid materials. Since graphite is also easily available in large quantities at relatively low cost, graphite blocks serve as moderator in most nuclear reactors.

3. *The Control Rods*

When properly arranged, the fission reaction continues automatically; no effort or attention is needed to maintain it. On the contrary, it must be kept from going too fast and too far. There must be some device for controlling its rate, for slowing it down, and even for stopping it entirely. This is very simply done in a reactor by providing rods or sheets of a material that stops and absorbs the neutrons that strike it without itself being altered or destroyed. Such materials are unusual but two fairly common metals do it nicely: boron and cadmium. Of these cadmium is the more practical. Reactors are therefore so built that cadmium rods can be inserted into the core from the outside and can be withdrawn or replaced

at will. When fully in place they "steal" the neutrons that are emitted in the spontaneous fission of a few fuel atoms, thus keep them from striking other uranium nuclei, and stop the reaction from going further. As they are gradually withdrawn from the core the chain reaction sets in and gathers speed. It can be maintained at any desired level by adjusting the position of the cadmium control rods and can be stopped almost instantly by inserting them to the full. As a safety measure, the controls are usually operated automatically by instruments that continually measure what is called the "neutron flux," or the number of flying neutrons that are active at any moment.

4. *The Coolant*

The primary product of the reactor is energy. It is released directly as two or three high-velocity fragments of each exploding uranium nucleus. They too collide with all the materials of the reactor and, because they are massive, atom-sized, set them into the rapid vibration that we call heat. They are thus stopped and gradually accumulate as chemical impurities in the core. Like ashes in a furnace they must eventually be removed. But that heat must also be removed if only to prevent the entire reactor from rising to an unmanageable temperature.

In the small and early reactors this was done simply by circulating a blast of air through them. Some large reactors today use compressed gases such as carbon dioxide. In others, large quantities of water are circulated through the reactors in pipes to keep the temperature down. In a large reactor a whole river may be needed. All this heat has been wasted in those reactors that are used primarily for the production of plutonium, for the

manufacture of special isotopes (see Chapter 6), for the study of the effect of neutrons on construction materials, or for other research purposes.

But a power industry based on nuclear energy must, of course, capture and use all this heat. It must be transferred from the interior of the reactor to a steam boiler or some other user of the heat. Air is not an efficient agent for gathering and then delivering heat. Water has the disadvantage that it boils at a relatively low temperature. A high-boiling liquid, such as mercury, is preferable because it operates at a high temperature and can thus transport a large amount of heat in a small volume of liquid. An alloy of the less common metals, sodium and potassium, is now in favor for this purpose.

The coolant is thus not merely a protector to keep the reactor from getting too hot. It is the essential link between the reactor that generates energy and the power plant that will convert the energy into useful form, as will appear in the next chapter.

5. The Shield

One additional feature is essential to every nuclear reactor, although it is not an actual working part of it. This is the massive shielding that must surround it on all sides to protect the operating personnel from the penetrating rays that are generated within. There are two dangers: the stray neutrons that escape at high speed in spite of every effort to retain and use them, and the "gamma" rays that are also generated in the nuclear explosions. These are true rays, not particles but very short-wave radiations much like X-rays but far more penetrating. Very brief exposure to neutrons can be fatal and gamma rays merely require somewhat more time to

become fatal, too. A shield some seven feet thick of solid concrete is therefore placed on all sides of every reactor to absorb these perilous rays. Somewhat less steel or lead may be used but the absorption must be done by a massive wall of heavy atoms and cannot be done by anything less.

It is this shield that makes even a small reactor look impressively large. It is also the reason why nuclear reactors will not be used as such to propel automobiles or to heat small houses. The heavy shielding is feasible only in large power installations.

Plutonium Production

Of the many special types of reactors that are now operating, the first and still the most important is one in which power production is not the primary purpose but the nuclear reaction that turns ordinary uranium-238 into plutonium. This element does not exist in nature, but, when made artificially from uranium, it is a fissionable nuclear fuel equal in value to uranium-235. Thus useless U-238 is made usable and the available nuclear fuel supply of the world can be multiplied one hundred forty times.

The process is simple in theory, as was described in Chapter 2. The U-238 nucleus absorbs a neutron from the disintegration of U-235, thus becomes U-239 which in turn automatically and quickly turns into plutonium. But in practice it requires careful management so that as many of the neutrons from the U-235 as possible are absorbed by the U-238. Each U-235 nucleus, on exploding, forms two or three neutrons (an average of about 2.5). One of them must explode another U-235 nucleus to maintain the reaction. If more fuel is to be produced than

is consumed the other one or two must both be effective in producing plutonium. This means avoiding all loss of neutrons and also careful use of the moderator so that it will slow the neutrons down to just the velocity at which they are most likely to be captured by the U-238 nuclei. As the plutonium accumulates in the core, thoroughly mingled with the uranium, there comes a time when the core must be removed for the chemical separation of the two, an operation of extreme difficulty because of the intense radioactivity of the other nuclear fragments in the core (see Chapter 6).

The Breeder Reactor

Since the reactor for making plutonium generates heat and any reactor designed for the production of heat and power can also produce plutonium, one of the most interesting and important reactors is one that combines the two—hence generates power for commercial use and at the same time produces plutonium. If it can produce one atom of plutonium for each atom of U-235 used, it uses in effect no fuel, for it replaces all that is used. In fact such a reactor has been operated for three years by the U.S. Atomic Energy Commission and has been shown to produce *more* fuel than it uses. Since it "breeds" fuel it is known as a breeder. Its value lies in the possibility of making and selling the valuable plutonium as a by-product of the power production, thereby reducing the cost of the reactor operation and, eventually, the cost of nuclear power.

A power generator that produces more fuel than it uses is not only one of the many extraordinary features of this new nuclear world but is also one of several unique factors that encourage the expectation that the

use of nuclear reactors will sooner or later replace the present power plants that use coal as fuel.

Special Types

A large number of special reactors have been built as experiments. In one the rods of uranium fuel are replaced by a solution of a salt of uranium (the sulfate or nitrate) in water, which thus combines the fuel and the moderator in a single "soup," cooled by water flowing through a coiled pipe in the steel pot. In another the core and moderator are suspended in a pool of water twenty feet deep to serve both as coolant and shield. In still another a solution of uranium salts in water is used for all three purposes: fuel, moderator and coolant. Other variations use pure U-235 in the core, or enrichments of natural uranium with different percentages of U-235, or finally natural uranium itself. One recent reactor uses the very light metal, beryllium, as moderator in place of graphite or heavy water. One important reactor has the sole purpose of testing the effect of neutron bombardment at high temperature on various types of steel, zirconium and other metals in a search for structural materials that will last longer or will withstand higher temperatures than are at present possible. One reactor is designed to produce an intense "neutron storm" for use in transforming common materials into their radioactive isotopes to be used in medical and other researches. All this indicates that the experimental period of reactor design is not yet over and that new discoveries and new designs will yet effect radical improvements in future reactors.

CHAPTER 5 *Power*

The Need of Power

THE INCENTIVE for the development of nuclear energy as a source of industrial power is strikingly revealed by a comparison of the average annual income per person in several typical countries with the average annual consumption of energy. There are several present sources of energy: coal, petroleum, natural gas and water power. But for the comparison the last three can be calculated in terms of coal and included as coal. Thus the coal consumed per person in the United States is 8 tons per year; in the United Kingdom and in Norway it is 4.5 tons; in Japan, 1 ton; and in India about a tenth of a ton. In comparison, the average income per person in the United States is about $2,000; in the United Kingdom and Norway it is $1,000; in Japan, $100; and in India approximately $50. These figures are not precise but they reliably establish the fact that a high standard of living is closely related to a high consumption of energy.

The disparity among nations is striking. In this day when all nations meet equally in the United Nations it is a strong incentive for raising the standard of living

everywhere. And that means not only increasing the food supply and the public health but, equally, the energy supply. The first of these is the concern of the Food and Agricultural Agency of the United Nations; the second is that of the World Health Organization; and the third, since it is largely a task of education, of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Most of the nations that use little energy also have inadequate resources in present-day fuels. But if the standard of living of all peoples were to be raised to the level of the highest, the known coal and oil deposits of the entire world would suffice for only about twenty years. The known resources of uranium and thorium, however, would serve for 500 to 1,000 years. Furthermore, dependence on coal would mean an impossible expenditure merely for the transporting of thousands of millions of tons of coal per year from the mines to the distant centers of use. Since one ton of nuclear fuel is equivalent to 2,500,000 tons of coal, the transportation problem would also be solved by the turn to nuclear fuels. These are the fundamental reasons for the interest of the United Nations in the prospects for nuclear power.

Production of Steam

Further research may eventually make it possible to convert the energy of flying neutrons and of larger nuclear particles directly into electricity. At present, however, the nuclear reactor delivers that energy as heat in the cooling liquid so that the task of power production is to capture the heat from the coolant and turn it into electricity, the most convenient form in which energy can be used at a distance. But the conversion of heat into

electricity is standard practice at any electric power station that uses coal. Indeed, the only difference is the source of the heat.

A modern electric power plant generates the electricity in gigantic spinning dynamos which are set spinning by the velocity and pressure of falling water in a water turbine or by the temperature and pressure of steam in a steam turbine. In the case of steam, high efficiency—which means low cost—is obtained if the pressure, and therefore the temperature, of the steam is high. In ordinary practice a steam plant that operates with steam at a pressure of 200 pounds per square inch must use twice as much coal as one that operates at 1,200 pounds of pressure. At the higher pressure the temperature of the steam is more than 1000°F. This is the reason for the engineer's desire to operate the nuclear reactor at the highest possible temperature and to use a cooling liquid that brings the heat to the steam boiler at a temperature of 1000°F. if possible. And this, in turn, is the reason for the present intensive search for new construction materials, such as the metal zirconium, to be used in the construction of reactors, and the quest for better liquid metal to serve as coolant. Such materials must withstand not only high temperature but also intense bombardment by neutrons in the reactor without losing their strength or other qualities. Zirconium is an excellent replacement for steel and serves well. But, being new, it is expensive. Its price has dropped from $300 a pound to $15 a pound within a few years and will no doubt fall still lower as its output increases. This is an example of the engineering problems that are encountered by the new nuclear power industry.

There is also the further difficulty that the cooling liquid, fiercely bombarded by neutrons while it is in the

reactor, itself becomes radioactive (see Chapter 6) and, therefore, dangerous to personnel by its emission of penetrating rays. For this reason it is common to pump it from the reactor to a "heat exchanger" where it is cooled by a second circuit of cooling liquid which thus becomes very hot but not radioactive. This second coolant then passes to the boilers where it converts water into high-pressure steam to operate the steam turbines that in turn spin the dynamos and generate electric power.

Costs

The success of nuclear energy as a source of industrial power—indeed, its very existence—will depend on the cost of the power produced. It is apparent that in countries where coal must be imported, especially after transportation over long distances, it will be cheaper than present power. Where coal is cheaply available nuclear power will probably cost more, at least for the present. The comparison and choice must be local because the cost of coal is a local matter.

But an estimate may be made. To begin with, the actual cost of generating electricity from steam is the same as in a present-day steam-electric plant of the same size because there is no difference in the operation or in the equipment required for that phase. The difference lies only in the cost of generating the steam. That cost has three major items: cost of fuel, cost of maintenance and the investment required.

Nuclear power has the advantage that the cost of the fuel is negligibly small. It is true that the cost of fissionable U-235 is very high (at least $10,000 a pound), but this is merely part of the investment since, on the breeder principle, it is constantly replaced by new plutonium

which is just as effective as U-235. The fuel cost is thus merely that of the ordinary uranium used in making plutonium. The cost of uranium is about $35 a pound, and 20 pounds of uranium will produce 52 million kilowatt-hours of electrical energy—enough to suffice a fairly large city for a year. The cost of the fuel itself is therefore only $0.000013, or 0.0013 cents, per kilowatt-hour. The usual cost of electricity is approximately $0.01, or 1 cent, per kilowatt-hour and so the cost of the fuel itself is so close to zero that it is negligible.

But the reactor requires several costly items of maintenance that the coal-fired steam boiler does not. After it has been in operation for some time—a year or more—the accumulation of the fission products in the core becomes an obstacle to the efficient use of the neutrons and the fission products must be eliminated. This requires removal of the entire core and its purification from such impurities by a difficult and costly chemical process. This cost has been estimated at about ten times the cost of the fuel itself, or roughly 0.013 cents, which is still very small, only a little more than one percent of the usual cost of electric power. In fact, the plutonium which is also a result of reactor operation can be removed and purified at the same time. If the reactor is a successful breeder the quantity of plutonium is larger than the original charge of U-235 and the excess may then be sold at a price which will compensate for the cost of this chemical operation. Even the unique maintenance cost of a reactor is therefore not high.

It is the amount of investment required to build a reactor that is high, very much higher than that of a coal-steam plant. In the United States, where most present reactors have been built, a coal-burning electric plant costs about $130 per kilowatt of electrical output, while

a nuclear plant costs at least twice as much to build. One 60,000 kilowatt nuclear plant, now under construction, is estimated to cost about $30,000,000 instead of about $7,000,000 for a coal-burning plant. The cost of the reactors will certainly be reduced as experience in their operation is gained and design is improved by further research. But for the present it can be said that because of the large construction cost, the cost of nuclear power is probably somewhat more than the cost of power from coal wherever coal is plentiful and cheap, but is certainly less where coal is costly. The upper limit for "cheap" coal would seem to be about $10 a ton.

Uses

The use of nuclear power in industry and commerce is just beginning. Several of the experimental reactors in England, Canada and the United States that were built for other purposes—such as the breeder reactor in the U.S.A.—have, incidentally, been used to generate power for their lighting system, for instance, and that of adjoining buildings. The U.S.S.R. has announced that "the first industrial power station run on atomic energy, with a useful capacity of 5,000 kilowatts" was put into operation on June 27, 1954, and "generated electricity for the use of industry and agriculture in the neighboring districts." In June, 1955, Mr. G. M. Malenkov, Minister of Electric Power Stations said informally that a full-scale 50,000 kilowatt station would be in operation very soon. In England a 50,000 kilowatt plant began production early in 1956. In the United States a 60,000 kilowatt plant has also been begun. France, Canada, Norway, Holland, Belgium and Switzerland are all planning on the construction of industrial power plants.

The confidence thus expressed in the commercial possibilities of nuclear power is based on the successful operation of a U.S. submarine which uses the first large nuclear generator. It was built before the costs of operation were known because of its additional advantage for naval purposes that its engines need no air and the ship can remain submerged for long periods. A second military advantage of nuclear engines has now also led to the design of nuclear naval and commercial vessels, namely that such ships do not need refueling because the uranium core of the reactor can continue to supply energy for thousands of miles and for many months or years. It is this same advantage that is now leading to the design of nuclear-powered airplanes which, if successful, will have an unlimited range in the air because they do not need refueling. The problem of lifting a heavy nuclear reactor and providing enough heavy shielding to protect the crew of the plane has not yet been solved.

CHAPTER 6 *Radioactivity*

Natural Radioactivity

FISSION IS the term applied to the sudden violent disruption of the individual nuclei of certain heavy atoms (of uranium-235, uranium-233 and plutonium-239) when they are struck by a high-velocity neutron and thereupon fly apart into two or more fragments which are themselves the nuclei of atoms of moderate mass (usually from 80 to 140 units). It is not a continuing process of nature, though it probably occurs whenever the sensitive atoms are hit by cosmic rays.

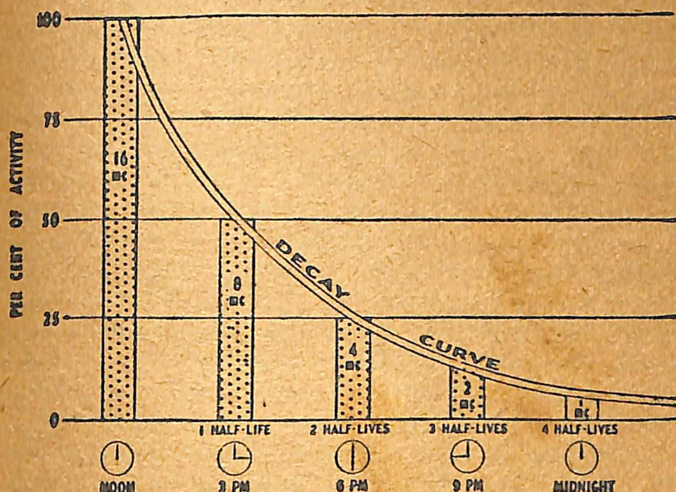
Radioactivity is a somewhat similar process in that it also involves nuclear disintegration, yet it is totally different in cause, mechanism and effect. It was discovered in ordinary uranium by Henri Becquerel as long ago as 1896 and the best-known example of it is given by radium, discovered by Pierre and Marie Curie two years later. The nuclei of all radioactive atoms are inherently unstable and sooner or later disintegrate of their own accord. The process is so completely automatic that,

even today, no human device is able to speed or retard its rate. In every radioactive element a certain small proportion of the atomic nuclei disintegrate in every second. When this fraction is large the activity is intense and all the atoms may break up and change to something else within a second, or, in other cases, in a matter of minutes or hours. When the fraction is small, the radioactivity is weak and the radioactive element may endure for years or centuries. The most convenient measure of the degree of instability of the atoms, and hence of the intensity of their radioactivity, is the time it takes for any given amount of the element to be reduced to half that amount. Radium, for instance, disintegrates at such a rate that a gram of it will be reduced to half a gram in 1,590 years. This is known as its "half-life." That of uranium is 4,000 million years, while for polonium it is only 136 days.

The other major distinction between fission and radioactivity is that in the latter the nucleus is not split into major nuclear fragments but undergoes only the ejection of small chips, either an "alpha particle" (the nucleus of a helium atom, composed of two protons and two neutrons, all four firmly bonded together) or an electron. Because they are emitted at high speeds and proceed in straight lines they have come to be known as rays—respectively alpha rays and beta rays, the beta being electrons. The emission of an electron is, however, always accompanied by a burst or pulse of penetrating wave radiation, quite similar to X-rays and known as "gamma rays" that stream out in all directions like light from an electric bulb.

When an alpha particle or an electron is ejected from a nucleus the electrical charge on the nucleus is changed, which also alters the number of electrons that can be held in the atom's exterior layers and thus changes its

chemical properties. In this manner all radioactive elements disintegrate into a succession of other elements, most of which are also radioactive and therefore temporary. But all of them also have the heaviest known atoms, beginning with uranium and thorium. After successive losses of alpha particles the nuclear masses are gradually reduced to that of lead 208. Lead, however, is



stable, not radioactive, and no atoms lighter than lead are naturally radioactive, with only a very few and weak exceptions.

All this was well known when nuclear fission entered on the scientific scene. In fact the existence of natural radioactivity showed that the atomic nuclei, of these heavy atoms at least, must be charged with concentrated

energy in order to eject such powerful rays. In this sense the understanding of radioactivity paved the way for that of fission.

Radioisotopes

But, unexpectedly, nuclear fission has now greatly increased the occurrence and the importance of radioactivity because the intense nuclear storms within the reactor cores can transform nearly every variety of atom into a radioactive form. This includes, of course, those nuclear fragments of uranium which accumulate in the core of a reactor and which may be subjected to bombardment for long periods by a neutron flux of a million million neutrons per second through every square centimeter. They may either absorb neutrons or lose them in such collisions, thus either gain or lose mass without changing their chemical properties and the resulting atoms are thus isotopes of known chemical elements. Examples are barium (Ba-140), krypton (Kr-94), molybdenum (Mo-103), and tin (Sn-131), shown on page 68. They need not be radioactive, but of the 1,300 presently known isotopes of the 101 known elements about 800 are radioactive, hence are called radioisotopes.

It is the accumulation of these isotopes in the reactor that makes the core—indeed all the materials in a reactor—so "hot" and so difficult to handle and to purify after the reactor has been in operation for a time. The removal of the radioisotopes and their disposal is one of the major problems of the new nuclear power industry because the intensity of the radiation is equal to that from tons of radium and is fatal to every living thing. They must, therefore, be handled only by remote control, with heavy walls to absorb the rays between the materials

and the operators at all stages. The final problem is where to put such waste products, at present useless, so that they will harm no one, not only now but in centuries to come. They are at present buried deep in the earth with the location carefully marked.

Similar radioisotopes are produced in smaller quantity by the explosion of the atomic bomb and are swept high into the sky and spread over a large area of the earth's surface, spread so thin as to be harmless except close to the explosion itself.

This radioactivity comes from many different isotopes with a wide variety of half-lives. Some of them last only for seconds or minutes. During that period they are intensely radioactive, but after an hour or two a large part of the radioactivity has already been lost. After two or three days it is greatly reduced by the disappearance then of the radioisotopes with a half-life measured in hours. The residue, however, disappears only slowly in the course of years.

Use of the Rays

The radioisotopes that are the by-products of reactor operation are of little use today because of the difficulty and cost of separating those with effective rays and long half-lives from the mixed isotopes. But the purified isotopes would have important uses if their cost were low. As nuclear power reactors become more common, it is probable that inexpensive methods of purification will develop and that the sale of the isotopes will provide an additional source of income to the power industry. A study made by the Stanford Research Institute in the United States for the U.S. Atomic Energy Commission has estimated that the impure fission products could be

produced at a cost between $0.02 (or 2 cents) and $2.00 a curie. Since a curie is the amount of radiation given off by one gram of radium formerly worth $100,000, this is a measure of the new age in radioactivity. The same study further estimates that pure individual radioisotopes could be produced at a cost of between $1.00 and $100 a curie and that as many as 30,000 curies would be obtainable from each pound of the mixed impure reactor materials.

Such costs would make possible many industrial and commercial uses of the radioisotopes. Some are, indeed, already established, such as the use of radioactive strontium (or as commonly written: radiostrontium) for the activation of luminous phosphors on the dials and clocks and watches and on road signs and other such markers. Another such use is in devices that eliminate the danger of static electricity where there is hazard of fire from electric sparks (because the rays make the air a conductor of electricity). At a price of $5.00 a curie radiocesium could be used in large quantities in place of X-ray machines for the shadow-photography of metals in industry.

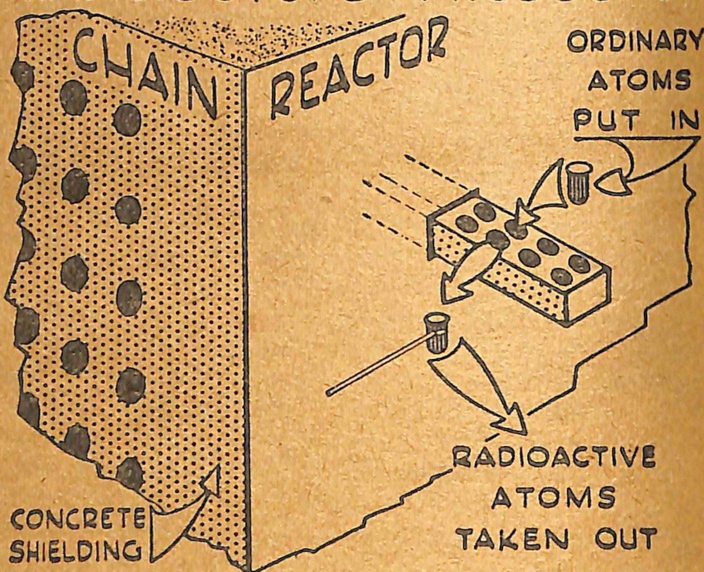
Probably the largest future use that could use millions of curies is in the sterilization, without heat, of drug and food products. At $2.00 a curie the radioactivity can be used for the sterilization of penicillin, for instance, which must be free of all bacteria or other sources of infection yet cannot be heated to destroy them. Only a short exposure of the drug to radiation renders it sterile but has no effect on the drug itself. At $.20, or 20 cents a curie the rays can be used to destroy the trichina parasites of pork or to sterilize canned meats, while at the improbable price of one cent a curie the isotopic rays could even be used to sterilize vegetables so that they could be kept in the open for some weeks without danger of spoilage.

Pure Isotopes

A large number of pure radioisotopes have been available for some years, made quite simply by inserting a small quantity of the desired element, or of one of its chemical compounds, into a cyclotron or a nuclear reactor through a tubular orifice and thus exposing it to neutron bombardment for the length of time (usually a matter of hours) required to convert it into the desired radioisotope. Examples are radiocarbon (C-14) and radiophosphorus (P-32) as shown on page 69. In this manner it is possible to manufacture special isotopes chosen for their chemical properties or for a long-enduring faint radiation or for a relative short-lived but intense radioactivity. Of the 800 known radioisotopes, 150 are useful and stable enough to be kept in stock for sale. Their use as "tracers" in biological, medical, agricultural and industrial research will be discussed in the next chapter. Since 1946 the U.S. Atomic Energy Commission has made more than 72,000 shipments of radioisotopes for use in about 2,700 institutions in the United States and about 4,000 shipments to some 660 institutions in 46 other countries. The government reactors in England, France, Canada and the U.S.S.R. have done as well.

Radium has long been useful in the treatment of cancer because its powerful rays destroy living tissue in brief exposure. Its value for this purpose justified a cost of $100 a milligram, which is $100,000 a gram, though it was very seldom to be had in quantities as large as a gram (about one thirtieth of an ounce). Today radiocobalt, manufactured in a reactor, has taken its place. Its cost is about $5.00 for an amount equal in radiation to a gram of radium and it can be had in large quantities.

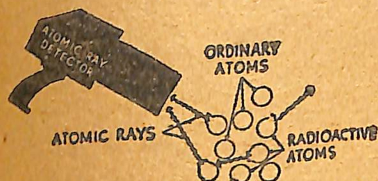
At least one U.S. hospital has a radiocobalt source whose radiation equals that of a kilogram, more than two pounds, of radium which is almost half the entire amount of pure radium ever produced. One great advantage of radiocobalt over radium is that it can be formed into any desired shape, such as plates for use outside the body, or complex shapes to fit different body locations, or into needles or beads of any size for insertion into the body, or even into a cobalt-nylon thread for insertion into a cancer. This shaping can be done with the stable, non-radioactive isotope of cobalt which is then converted into radiocobalt by exposing it to neutrons in a reactor.



Other pure isotopes are used in medicine partly for their special chemical properties. The thyroid gland, for instance, absorbs and uses iodine, and any iodine taken in with food or drink lodges there. But if a patient suffering from an overactive thyroid gland, a disease known as hyperthyroidism, is allowed to take a small quantity of radioiodine, it goes to the thyroid and its beta rays bombard and damage sufficient thyroid cells to reduce the abnormal activity. Similarly an isotope of boron accumulates in one type of brain tumor and can there be made radioactive by a brief exposure to a neutron beam and then destroys the tumor. Ordinary phosphorus compounds are used by the body to build bone tissue and if a patient is given radiophosphorus it too goes to the bones. There it has been effective in reducing the production of red blood cells by the bone marrow and thus in alleviating the disease known as polycythemia vera in which there is an overproduction of red blood cells. Efforts to find a radioisotope that concentrates in cancer cells have

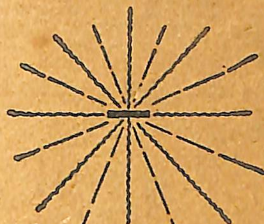
RADIATIONS FROM RADIOISOTOPES MAKE THEM USEFUL

1 FOR TRACING ATOMS



LIKE PUTTING "TAGS" on ATOMS

2 FOR RADIATION SOURCES



LIKE RADIUM or X-RAYS

so far been unsuccessful in spite of much research directed toward developing what would be a simple cancer treatment that would destroy internal cancers without surgery.

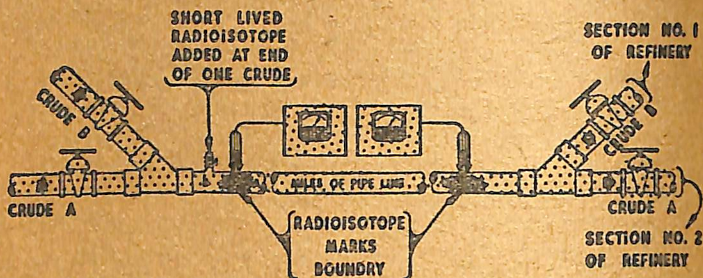
All the uses of radioisotopes mentioned in this chapter are actually uses of their powerful rays and require adequate quantities to exert their action. By contrast, the next chapter discusses the use of radioisotopes in extremely small quantities and with very weak radiations, just strong enough to be detected by sensitive instruments, not nearly strong enough for their rays to have any effect whatever. They are thus used as "tracers" in many types of research.

CHAPTER 7 *Tracers*

In Industry

THE WORD "tracer" has come into use in English to designate the ability of the radioactive isotopes of common chemical elements to reveal their presence by their rays, which permits the observer to follow or trace their travels or adventures, whether it be the flight of a mosquito, the flow of oil in a pipeline or the course of the carbon atoms in a lump of sugar through the human body. The phenomenon is not so much like observing a tracer bullet in flight as it is like following the adventures of a spy behind enemy lines, or of an explorer in the jungle, by listening to his own account over a portable radio transmitter. This new technique has once more enhanced man's ability to observe things and events that his own unaided senses cannot detect, as did the microscope, the telescope and the radio receiver.

The method depends on the fact that nearly all the common chemical elements can now be obtained in the form of suitable radioisotopes. They include carbon, phosphorus, sulfur, iodine, and many metals. The isotope undergoes exactly the same chemical reactions as does



the normal element and so can be built into any number of chemical compounds. Thus radioactive carbon dioxide, for instance, can be used by green leaves to make sugar or starch, which is then slightly radioactive. These foods can be eaten and the fate of the food can be followed by using delicate instruments to locate the source of rays. Most of the radioisotopes now produced are used for such biological and medical researches.

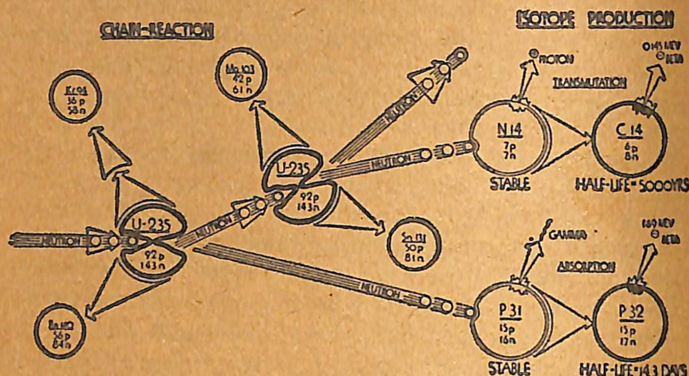
The simplest use, however, is to trace transportation or mechanical actions such as friction. The transport of petroleum and its products is now commonly done by pipelines that may be hundreds of miles in length. It is now possible to use the same pipe for pumping different oils in succession: motor fuel, lubricating oils or crude petroleum. In order to mark the end of one oil and the beginning of the next, a small amount of oil-soluble radioisotope is injected when the change is made at the start of the pipeline. The arrival of the junction is signaled at distant end of the pipe by the arrival of the rays, which penetrate the pipe and are detected by instru-

ments. The operator can then adjust the valves to separate the new oil and send it to its proper tank.

A similar use protects the hands of a machine operator from contact with danger: the operator wears a bracelet or wristband which has been made slightly radioactive and the machine is provided with a detection device. When the hand comes near enough to be in danger, the rays are detected and a warning flashes or the machine stops.

Most typical are the uses of radioisotopes in research studies. The measurement of friction in machine parts, and thus the study of the effectiveness of lubricants, has always been long and costly because a machine or an engine must be operated for long periods before the loss of metal from a piston ring, for instance, can be detected by weighing it. But if the ring is made slightly radioactive by the use of radioisotopes, the wear can be detected and measured in a matter of minutes when the abraded radioactive atoms begin to show themselves in the lubricant. Not only is the cost of the research thus greatly reduced but the resulting improved metals and lubricating oils go into use years earlier.

Hundreds of similar uses might be listed. Resistance to wear has been thus tested on shoe soles, floor waxes, road surfaces, automobile tires, paints, and concrete as well as on many metals. Methods of electroplating silver have been improved. So also has the quality and effectiveness of soaps and detergents, toothpastes and even cosmetics. Such difficult problems as the measurement of the penetration of preservative chemicals into a telephone pole or other wooden beams have become simple. All such uses are examples of tracer action in which a relatively few radioactive isotope atoms reveal what is happening to all the countless other atoms because these few can "talk" by means of their rays.



Production of Radiocarbon and Radiophosphorus in a Reactor

A neutron from the fission of uranium strikes an atom of nitrogen, knocks out a proton and takes its place in the nucleus. Result: the weight remains the same (14), but with only six protons the nucleus can hold only six external electrons and so has become an atom of carbon. It is weakly radioactive, gives off beta rays that can easily be detected, has a long half-life, so makes an excellent tracer when used in any compound of carbon.

Another neutron strikes an atom of ordinary phosphorus, simply adds on to it, thus increases its weight from 31 to 32. P-32 is also radioactive and emits beta rays for several weeks, thus is useful as a tracer.

In Agriculture

Similar researches in agriculture have been even more numerous than in industry and, if used the world over, would be far more valuable. Farmers everywhere must cope with a large number of unknown factors even when their information is of the best, so that many of their

methods are still based on tradition rather than knowledge. An example is in the use of fertilizers which are a major item in the cost of food production. Here radiophosphorus (P-32 to chemists) has proven invaluable. Used as phosphate fertilizer, it instantly reports what the plant has done with it.

Thus Swedish investigators have found that phosphate in a fertilizer is taken up by the plant roots almost immediately when it is spread on the soil; there is no delay. American research men have proved that pasture grasses take up phosphate that is spread on their leaves and on the top of the sod so that there is no need for plowing. Very large savings were made by tobacco and cotton farmers after the discovery that these plants, together with maize and sugar beets, take phosphate from the fertilizer only during the early stages of their growth and that phosphate is wasted if it is applied later. On the other hand, it has been shown that potatoes can profit from phosphate fertilizer throughout their entire growth. Further, tracer researches have shown that phosphoric acid added to irrigation water is just as effective as dry phosphate spread on the soil.

Within the past few years new chemical sprays have come to the aid of the farmer in destroying both weeds and insects. Their actions on the plant or the insect are not as yet understood, largely because in both cases very small quantities have fatal effects on these enemies of the farmer. Improved sprays are expected from present studies that use radioisotopes. For instance, the weed-killers are chemicals that kill the broad-leaved weeds without harm to the large family of narrow-leaved grasses, which include all the cereals. It has now been determined that they do so because they are rapidly ab-

sorbed by the broad leaves and permeate the entire plant within two hours while, in the case of the grass leaves, they stay on the spot where they are sprayed and do not go farther. For another instance, there are insecticides which are sprayed on plants, then kill the insects that suck the plant juices. Radioisotope studies have shown that such insecticides are absorbed into plant leaves only by day and only on the under side of leaves.

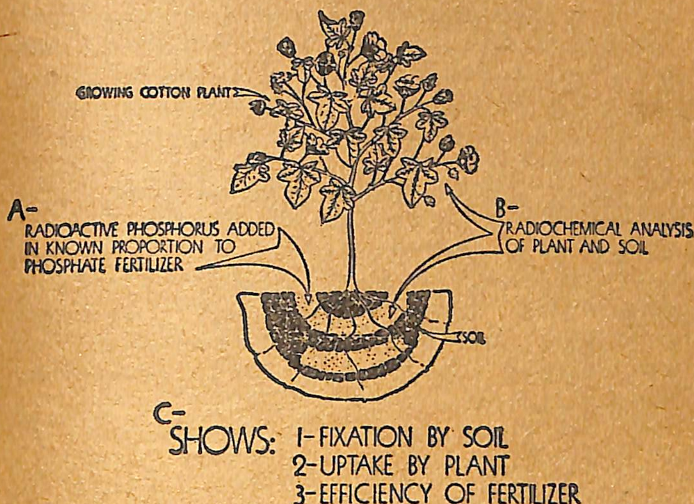
Even flies, mosquitoes and locusts have been made radioactive by feeding on materials that contain radioisotopes and, thus marked for identification, have betrayed their habits and flight pattern, which has then led to better control. The resistance of certain insects to insecticides has been explained by their ability to break the toxic chemicals down into harmless ones and has thus shown the way to the use of new and more fatal insect poisons.

In Biological Research

The earliest, and now classic, research with the tracer technique was done by Dr. Richard Schoenheimer in New York, in 1935, before radioisotopes were available. He used isotopes of hydrogen and of nitrogen that are heavier than the normal atoms and could be detected by their weight, much more laboriously than by present radioisotope methods. But that research set the pattern for a large number of later studies as to what happens in the chemistry of the human and animal body.

Dr. Schoenheimer proved that the substances which comprise the body are in a constant process of replacement so that in every twelve months the entire body is made anew. When fats are eaten they are not at once burned for their energy value but are deposited in the

P 32 STUDY OF PHOSPHATE FERTILIZER



fatty tissues while the body fats already present are used for energy production. Similarly the protein in foods is built into tissue, muscle and nerve cells while the old protein molecules are discarded, oxidized and excreted. The use of radioisotopes in recent years has confirmed this fact and added to it so that it is now well established that even the bones are thus constantly being rebuilt. Only the iron atoms in the red blood cells seem to stay in place. Except for them every person and animal is physically renewed at least once a year. No one is his old self for long. Neither philosophers nor poets have as yet celebrated this striking result of tracer research.

A recent research with chicken feed that had been marked with radioisotopes confirms this discovery in spe-

cific detail. Hens do not produce eggs from their food of today or yesterday but from what they ate more than a month ago. The proteins in the egg have meanwhile been proteins of the hen's body and are used for egg production only when discarded by the hen and replaced with new protein. But this is not true of the eggshell. When the egg is ready to be laid the shell is put on and is made of calcium molecules that were eaten by the hen that very day.

These are examples of the new knowledge that is coming from biological laboratories with the aid of radioisotopes. Much of it concerns the highly complex details of biochemical reactions within the living body and the living cell which cannot be explained in detail in a short and popular book. But the many chemical reactions which together constitute the life process were until recently quite beyond the reach of scientific investigation. Today the isotopes of carbon, hydrogen and other elements permit what is literally an insight into the secret internal operations and reactions of living cells and promise an understanding of the nature of the life process itself. Compared with the tracer technique, the microscope —which taught man so much of the structure of living things—is a crude and superficial instrument. It deals with cells, not molecules; and it reveals form, not function.

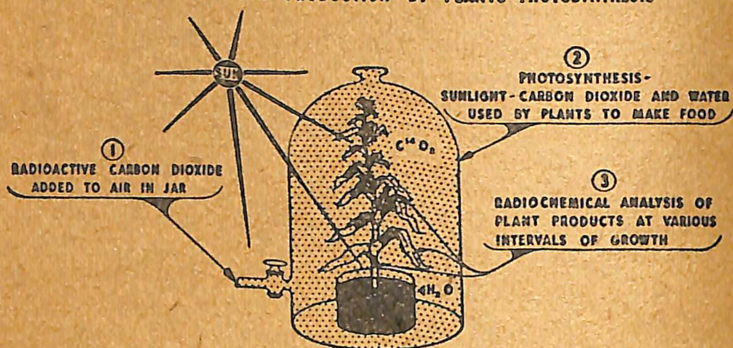
Photosynthesis

One more example may be given. The fundamental chemical reaction on which all life depends is the synthesis of plant materials from carbon dioxide and water by the energy of sunlight in the leaves of green plants. Without this reaction there would be no plants and with-

out plants animals would have no food; there would be no life. It is apparently a simple reaction, yet no man can accomplish it or even understand it. Once its mechanism is understood it should be possible at least to improve on it and thus to increase the natural food supply for the rapidly increasing population of the earth. At best, it should be possible to duplicate the reaction and manufacture food from sunlight without the intervention of green leaves. Plants are effective in the use of sun-energy, but they are not efficient. Less than one percent of the energy that falls on a field of grain or grass is actually used for the production of food. There is room for improvement, indeed for multiplication of the food supply and this may become a vital need in future centuries to keep pace with the multiplication of humanity.

It is thus important, though not yet urgent, to use the tracer method to study this reaction, and this is being done in a score of research laboratories in many lands. The radioisotope of carbon is easy to make in a nuclear reactor. Hence it is easy also to produce carbon dioxide which is tagged or labeled with a trace of radiocarbon dioxide. When this is released in the air of a greenhouse, or in a glass bell over a single plant, the innocent leaf uses radiocarbon dioxide without distinction from the normal isotope and thus itself becomes radioactive. The passage of the tracer from leaf to stem to root can easily be followed, which at once confirms the fact that plants are built of air, not of earth.

But what is more important is to take the leaf apart chemically and to learn which chemical constituents first contain the radiocarbon and thus the first step in the transition from carbon dioxide to sugar and starch. Actually the work is not done with complex leaves but with



simple one-celled green plants such as *Chlorella*, a species of algae. These cells work fast. After an exposure of only one minute they contain at least fifty separate compounds into which the radiocarbon isotope has already entered. After two minutes even complex proteins and fats already contain the new carbon just received from the atmosphere.

After an exposure of only two seconds to radiocarbon dioxide and to light only two or three compounds of the new carbon are present. These turn out to be complicated phosphoglyceric acids which apparently are present in the green cell to take both the carbon dioxide from the air and the energy that is absorbed from the light by the green chlorophyll. So much is now known. It is not yet

clear how the oxygen is then detached from the carbon of the dioxide and the carbon is used for plant-building. But step by step this apparently simple, actually complex, fundamental life-reaction is being analyzed and must soon become quite clear. The radiocarbon will tell the whole story sooner or later.

It is in purely scientific studies of this sort that the radioisotopes play their finest role. They are by-products of nuclear fission. The main product is energy and the prime objective of the new reactors is power for the immediate improvement of living conditions of mankind. But the by-product is scientific understanding of the processes of the universe and of life. For future generations and in the perspective of history the new knowledge will be at least as valuable as the new energy and probably much more valuable.

CHAPTER 8 *Prospects*

A New Science

THIS BRIEF INTRODUCTION to the principles of the nuclear science and to the uses of the new energy and materials indicates that we have here much more than a simple scientific discovery. It is a whole new science that has been created and given the name of nucleonics just as the study of the myriad phenomena of electrons is now called electronics. It is, however, not merely a branch of physics but a junction at root level of physics and chemistry with branches in biology, archeology and even cosmology. A half-century ago the atom was considered to be a hard, impenetrable particle, whose interior was unknowable. Today it is a universe in itself and it is certain that its nucleus, far smaller than the atom, is not ultimate but is complicated in material, concentrated in energy. Within it lies further mystery, in particular the secret of the exact mechanism of the conversion of matter into energy—and possibly of the reverse, the conversion of energy into matter. Are they perhaps merely different aspects of some deeper, primordial reality, which is the very stuff of existence? How far can research go inwards?

Such questions reveal that nucleonics is still in its infancy and that present knowledge is only preliminary.

It is for this reason that it is important to realize that all the reactors are but impressive engineering applications of what science knows today. They have as much ignorance built into them as they have of knowledge. They were designed and built on facts and ideas that came from esoteric laboratory researchers that, over a period of fifty years, had learned to penetrate and explore the atom and then the nucleus. Not one of the explorers could have visualized a reactor until, in 1940, the new knowledge was put together into a design.

International Prospects

The sequence is an international story. It began in 1895 with Roentgen in Germany, who discovered the X-rays that pass readily through apparently solid matter. In 1896 Becquerel in France discovered such rays coming naturally from uranium and its minerals. In 1898 Pierre and Marie Curie, also in France, found a powerful source of complex natural radiations in radium. Then came Rutherford of Canada who in 1902 explained radioactivity by the spontaneous disintegration of atoms, then, in England in 1911, proved that the atom must have a nucleus, and in 1919 broke a single fragment from a nitrogen nucleus by bombarding it with alpha particles. Rutherford's conception of the nuclear atom was elaborated into a detailed and accurate theory in Denmark, by Bohr in 1913. Meanwhile, Einstein, in Germany in 1905, published his mathematical theory of relativity which included the concept of the equivalence of matter and energy and hence the possibility that one could be converted into the other. This was experimentally con-

firmed by Cockcroft and Walton in England in 1932.

The pace of research increased when Lawrence, in the United States in 1932, developed that extraordinary machine, the cyclotron, which imparts velocities which approach that of light to electrons, protons and other nuclear particles and can thus hurl them with tremendous energy at other target nuclei to produce nuclear reactions. Most of present knowledge of these reactions was supplied by a large number of powerful cyclotrons in many countries long before a nuclear reactor was built, or could be designed.

In 1932 also, in England, Chadwick discovered the neutron. In 1933 in France, Irène Curie, daughter of the discoverer of radium, and her husband, Frédéric Joliot, first produced radioisotopes artificially, and in 1934, in Italy, Fermi used the newly discovered neutrons to bombard atomic nuclei. Finally, late in 1938 in Germany, Hahn and Strassmann used neutrons to bombard uranium and discovered not only the break-up of the uranium nucleus into two major fragments but also the tremendous energy carried by these fragments. Within a month, in the first days of 1939, in Denmark and in Sweden, two German refugees, Frisch and Miss Lise Meitner recognized the significance of this discovery and called it nuclear fission. The world was ready for the nuclear age—and unfortunately for war at the same time.

It was thus the existence of brilliant research scientists and of adequate research facilities for them in many countries that gradually provided all the necessary knowledge as a natural consequence of the scientist's quest for understanding the atom. It was military necessity that provided the incentive. It was the engineering and organizational skill and the great industrial power of the United States, plus the courage to spend thousands

of millions of dollars on an untried experiment, that provided the resources. Together, these three compressed perhaps fifty years of normal progress into five. In 1945 nuclear science and reactor engineering emerged full-grown on a stunned world. Ten more years of practical operation have now ensued the results of which, under the guise of fear and contrary to the spirit of science itself, have to a large extent been kept as the secret property of separate nations. Now at last it is realized the world over that while weapons can be kept secret until they are obsolete, the science of nucleonics offers enormously more than weapons and can be a treasure house for humanity.

The International Conference on the Peaceful Uses of Atomic Energy, sponsored and organized by the United Nations at Geneva in August, 1955, has provided a powerful incentive to those uses. The exchange of scientific and technical information among the experts from seventy three nations adds to the resources of each without detracting from any. International understanding should lead to international cooperation in the scientific and technical realm which the conference covers.

United Nations Action

Actual cooperation between governments in the development of nuclear power and nuclear science will await later action between the governments or by the United Nations. In his historic address to the General Assembly of the United Nations on the eighth of December, 1953, the President of the United States said in part:

> Peaceful power from atomic energy is no dream of

the future. That capability, already proved, is here now—today. Who can doubt, if the entire body of the world's scientists and engineers had adequate amounts of fissionable material with which to test and develop their ideas, that this capability would rapidly be transformed into universal, efficient, and economic usage?

I therefore make the following proposal: The governments principally involved, to the extent permitted by elementary prudence, to begin now and continue to make joint contributions from their stockpiles of normal uranium and fissionable materials to an international atomic energy agency. We would expect that such an agency would be set up under the aegis of the United Nations.

The formal resolution was submitted to the United Nations by seven Member States: Australia, Belgium, Canada, France, South Africa, the United Kingdom and the United States. It was endorsed unanimously by the Political and Security Committee of the United Nations on November 23, 1954 and was approved unanimously by the entire membership of the United Nations General Assembly on December 4, 1954. The resolution thus adopted expresses the hope that "international co-operation in developing and expanding the peaceful uses of atomic energy will assist in lifting the burdens of hunger, poverty and disease," and suggests that "once the agency is established, it negotiate an appropriate form of agreement with the United Nations, similar to those of the Specialized Agencies." The same resolution requested the Secretary-General to call what is now the scientific and technical conference at Geneva.

In this context and awaiting action by the "governments principally involved" to establish such an agency, the United States is making cooperative agreements with individual governments. The President has announced that the United States will offer research reactors to other nations "for the acquisition of the skills and understanding essential to peaceful atomic progress," will contribute half their cost and will furnish the acquiring nation the nuclear material needed to fuel the reactor. For such nations his proposal also includes "access to and training in the technological processes of construction and operation of the reactors for peaceful purposes."

Thus the spread of nuclear science and engineering among the nations of the earth in the immediate future and of nuclear power and its by-products later, seems already assured in advance of the establishment of an international atomic energy agency under the aegis of the United Nations. The nuclear age is gathering momentum.

Meanwhile the existing Specialized Agencies of the United Nations, whose broad purposes are to promote peace and improve the living conditions of mankind, have direct interests and duties in view of nuclear developments that may come swiftly enough to be called revolutionary. Three in particular are already in action: the World Health Organization (WHO) whose primary purpose is to combat disease and promote public health; the Food and Agriculture Organization (FAO) which combats hunger and malnutrition and improves agriculture, fisheries and forestry; and the United Nations Educational, Scientific and Cultural Organization (UNESCO) which combats ignorance and aids education and research in many fields.

FAO

In the field of food and agriculture, a few examples of the use of radioactive tracers have been mentioned in Chapter 7. The Food and Agriculture Organization of the United Nations has listed a large number of possible uses of radiations and radioactive isotopes under three headings. In agricultural processing and food technology the uses of rays include the preservation of food by sterilization without heat, including meat and fish, and the storage of bulk foods, such as grains which are subject to infestation by pests. In plant and animal breeding the use of isotopic radiations to induce mutations of inheritance and permit the selection of new and superior strains constitutes one of the most important potential contributions of atomic science in agriculture. Improved types of cereals and peanuts have already been obtained as well as types of grains that are better adapted to specific conditions of rainfall or soil fertility. In addition, the tracer technique has given impressive research results in crop production, animal husbandry, fisheries and nutrition and will be far more widely applied.

In a longer view the availability of more abundant and cheaper electric power from nuclear reactors will have a profound effect on agricultural production and on rural welfare in general. It will reduce costs, ameliorate working conditions and raise the standard of living of rural populations. Nuclear engines in the larger vessels of the fishing and whaling fleets would also improve the yields and reduce costs. In forestry, more and cheaper electric power would stimulate small and rural forest-product industries and also aid the major pulp and paper industries. And a "revolutionary impact" on the large semi-arid and desert areas of the world can be foreseen if eventually

inexpensive nuclear energy makes possible the desalting of sea water for use in irrigation.

WHO

The interest of the World Health Organization in the use of radiations and of radioisotopes, if not in the use of nuclear power itself, is direct, especially in the international aspects with which individual countries are unable to deal. The present program of WHO has two major items dealing with nuclear developments.

The first is the question of the protection of health against the hazards connected with the nuclear reactors, such as the contamination of water by liquid wastes, of air by volatile materials, and of the soil and the sea by the disposal of solid wastes. Related to this is the establishment of standards for radioactive materials and the accurate measurement of dangerous radiations. WHO will also provide expert advice in these matters and collect and disseminate scientific information on them.

The second is the use of radioisotopes in therapy, diagnosis and medical research. Here WHO will act as a clearing house for the exchange of information, and will develop long-term help to countries in training adequate technical personnel through fellowships, consultants, study tours and advanced training courses.

UNESCO

The challenge of the nuclear age to the United Nations Educational, Scientific and Cultural Organization (UNESCO) is both deeper and broader than that to its sister Specialized Agencies of the United Nations. It is deeper because science (the "S" in UNESCO) is at

the very bottom of every problem of the age; it is broader because a host of educational, scientific and cultural changes (the "ESC" in UNESCO) will inevitably follow the nuclear reactors—and sooner rather than later.

For the Geneva Conference on the peaceful uses of atomic energy UNESCO submitted two contributions. One is a summary report of the status of nuclear reactors for research purposes and an evaluation of the usefulness of such reactors to a university in view of local circumstances and in comparison with other nuclear research equipment such as electrostatic generators and cyclotrons. The other UNESCO contribution is a study of training of research personnel for the peaceful uses of atomic energy. It recommends that universities and technical colleges should include both theoretical and practical training in radioactivity and in electronics to meet the new demands but that highly specialized training, such as that for the operation of nuclear reactors, should be given in new training schools to be created by the nuclear establishments themselves.

The general interest in nuclear power and its probable economic benefits will, however, make demands far beyond the scope of scientific research and university studies. One of the first must be a stimulus to scientific education in the lower schools and to technical training in many parts of the world. Even in the industrialized nations there is already a grave shortage of competent science teachers. The sudden coming of a nuclear age will create an emergency demand for vocational training, for science teaching in the secondary schools and for the education of the teachers. The improvement of science teaching in the schools is a part of UNESCO's normal program, and its services will now be expanded particu-

larly in the underdeveloped countries that have most to gain from nuclear power but whose school systems have not yet been oriented toward modern science. Among these services will be manual and visual aids for the introduction of the facts and concepts of nuclear energy, radiation and radioactive materials into school science teaching.

In many nations nuclear power with all its consequences will come so fast that there will not be time to wait for the school children to grow to manhood. The large public expenditures needed will demand informed advance public support. The fruitful application of the results of nuclear research in medicine, agriculture and industry also require public understanding. Most of all, the economic and social consequences of the imminent power revolution demand foresight in government and a broad incorporation of science into local cultures. A forced nuclear economy could be dangerously incompatible with an unscientific culture.

This, therefore, implies a need for the education of the adult public of many nations at least in the elements of scientific thinking. UNESCO has long been engaged in the scientific education of the public by means of traveling science exhibits, by promoting out-of-school science activities, and articles and discussions in the press, the radio and the cinema screen. All of these will now include education in the fundamentals of the physical and nuclear sciences, as is shown by two recent special issues of the *UNESCO Courier* and by this little book.

A World Challenge

But what impends for the world in the nuclear age is far larger than the scope of science. Sir Winston Chur-

chill has called this a "turning point in our destiny," the destiny of mankind. The power to be generated is not merely electrical; it is economic and social power. The stream of electrons that will gush from the power stations could become the lifeblood of underprivileged peoples. It could water the deserts, turn underground resources into wealth, increase both health and the length of life and at the same time multiply food production. Nuclear power and its by-products may eventually have as great an impact on the pursuits of peace as the atomic bomb had on those of war. It is visionary to expect such results within a decade, or within several. But the challenge to mankind is to foresee and prepare so that the consequences be for the good of nations and be neither lost nor harmful. If it is a weapon of peace, its tactics are in the competent hands of scientists. But it demands a new strategy, too, in the plans of governments and of the international organizations.

Index: with Definitions

For quick reference, the more important scientific terms used in this booklet are here alphabetically listed, with the page numbers on which they are either first used or more fully explained.

Suggestions for Further Reading

"The World within the Atom," *UNESCO Courier*, Vol. VI, No. 12, 1953. A series of five articles on the structure of the atom, radioactivity, cosmic rays, cyclotrons, the European Council for Nuclear Research, and isotopes. An introduction to nuclear physics and high-energy particles with no reference to fission or reactors.

"Atomic Power—a World Picture," *UNESCO Courier*, Vol VII, No. 10, March 1955.
A special issue devoted wholly to 14 articles on the facts and prospects of the use of nuclear energy.

Report on the Atom, by Gordon Dean, former Chairman of the United States Atomic Energy Commission, published 1953 by Alfred A. Knopf, New York.
A 321-page book on the history and present status of the U.S. program in the development of atomic energy and atomic materials for war and peace.

Atoms for Peace, by David O. Woodbury, published 1955 by Dodd, Mead & Co., New York.
A 250-page "popular" book, written in the American vernacular, with much more news and current information and somewhat less serious instruction than is in this booklet.

The New Force, by Ralph E. Lapp, former scientific advisor to the U.S. War Department General Staff and later head of the Nuclear Physics Branch of the U.S. Office of Naval Research; published 1953 by Harper & Brothers, New York.
A 234-page book somewhat more than half of which reviews the ten preceding years of research and accomplishments in the military uses of atomic energy, and the rest forecasts the possibilities for peace.

Industrial Uses of Radioactive Fission Products, published 1951 by the Stanford Research Institute, Stanford, California, U.S.A.
A comprehensive and detailed 102-page report to the United States Atomic Energy Commission, which surveys from a scien-

tific, engineering and economic point of view the practical possibilities for the use of the fission by-products of the nuclear reactors.

The Peaceful Atom, published 1955 by the American Museum of Atomic Energy, Oak Ridge, Tennessee, U.S.A.

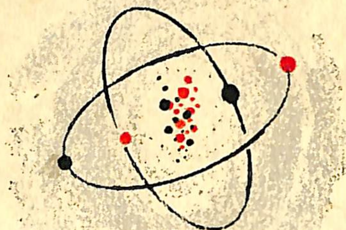
A brochure, well illustrated with photographs and explanatory drawings, of the simplest facts about nuclear energy, in very popular style.

Explaining the Atom, by Selig Hecht, published 1947 by The Viking Press, New York.

Written to give an understanding of the atomic bomb, its first six chapters are a review by an excellent teacher of atomic and nuclear science, somewhat more advanced than in this book, and a good sequel to it for those who want more details.

Though beginning with an explanation of the atomic bomb, YOU AND THE ATOM is not a book about bombs, war and destruction. In its approach to nuclear energy, it is much more exciting and far more affirmative.

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